

Fast-static GPS positioning with external tropospheric corrections derived in near real-time



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INTRODUCTION

The tropospheric delay of GNSS signals is considered as one of the most important error sources in precise positioning applications. It is usually parameterized as Zenith Total Delay (ZTD). Currently, the most popular solution in the state of the art applications is to estimate ZTD together with station coordinates in the common data adjustment. This approach requires long data spans, e.g., at least 30-60 minutes. However, in fast-static positioning when short data spans (a few minutes only) are available, this method is not feasible and accurate ZTD is very difficult to model. Therefore, fast-static positioning requires external tropospheric information in order to improve its accuracy. This can be achieved by a network of reference GNSS stations (Ground Based Augmentation System - GBAS), where ZTD can be obtained in near real-time (NRT) in the adjustment of GNSS data or directly from the ground meteorological data and provided as an external supporting product.

In this paper, we focus on the analysis of the application of two ZTD modeling techniques to fast-static GNSS positioning, namely: NRT ZTD estimates obtained based on GNSS data from Polish GBAS system (ASG-EUPOS) and IGS/EPN and IERS products, NRT ZTD determination based on meteorological data collected in real time from ASG-EUPOS, METAR and SYNOP systems. In order to assess the accuracy of these ZTD modeling techniques, test baselines of several tens of kilometers were processed in fast-static mode using the GINPOS software developed at UWM in Olsztyn. A 24-h data set was divided into 144 sessions, each of 5-minute long (10-epochs with 30 s interval). Each session was processed independently and the obtained coordinate residuals were analyzed. A special attention was paid to the height component accuracy. Five different approaches to the troposphere modeling were applied and tested in fast-static positioning: (1) using the official ZTD provided by the ASG-EUPOS system (also for the rover) – this was considered as a reference solution, (2) using the official ZTD provided by the ASG-EUPOS system, fixed for the reference stations and interpolated to the rover receiver, (3) using NRT ZTD estimates based on reference station GNSS data, (4) using NRT ZTD estimates based on meteorological data and Saastamoinen model, (5) using UNB3m troposphere model.

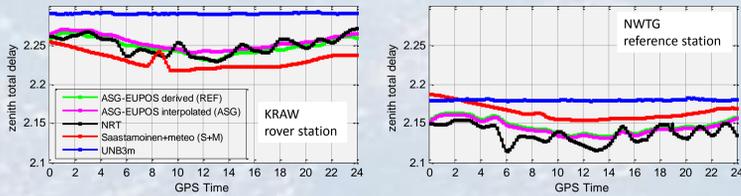


Fig. 1 ZTD from different models obtained for KRAW (rover) and NWTG (sample reference) station

$$\begin{aligned} & \begin{matrix} [k_y, h, T, P] \\ \swarrow \quad \searrow \\ W_1 \quad W_2 \\ \swarrow \quad \searrow \\ [k_y, h, T, P] \\ \swarrow \quad \searrow \\ W_3 \quad W_4 \\ \swarrow \quad \searrow \\ [k_y, h, T, P] \end{matrix} \\ & \text{Temperature: } s \leftarrow T \\ & \text{Humidity: } s \leftarrow H \\ & \text{Pressure: } s \leftarrow P \\ & \log P = \log P_{00} + \frac{1}{18400} \left(1 + \frac{h}{5555.6} \right) \end{aligned}$$

Fig. 2 Algorithm for computation of ZTD in near-real time from Saastamoinen model + meteo data

EXPERIMENT

Test data

- Dual-frequency pseudorange and carrier phase GPS data were processed. 24 hours of GPS data from ASG-EUPOS network were used (15 FEB 2012).
- KRAW station was selected as simulated user receiver, LELO, NWTG, ZYWI served as reference stations.
- Test data were divided into 5-minute sessions starting every 10 minutes – total number of 144 independent sessions per baseline were processed.
- Three baselines with different height differences ranging from 39 m (LELO-KRAW) to 379 m (NWTG-KRAW) were formed.
- Baseline lengths ranged from 65 to 72 km.

General processing scheme

- The GINPOS software developed at UWM was used for the processing.
- Dual-frequency pseudorange and carrier phase GPS data were processed.
- Observational data were processed in both single-baseline and network (multi-baseline) positioning modes.
- The ionospheric refraction was mitigated by introduction of corrections derived from the reference network solution together with the estimation of residual double-differenced ionospheric delays in the data adjustment procedure.
- The tropospheric ZTD from different models were applied and tightly constrained in the adjustment.
- The LAMBDA method was applied for the ambiguity resolution.
- W-ratio test with threshold of 2.0 (determined empirically) was used for the ambiguity selection validation.
- The obtained static positions were compared to the reference position (official ASG-EUPOS solution)

Troposphere modeling strategies

Five different approaches were applied and tested:

- 1) using the official ZTDs provided by the ASG-EUPOS system (also for the rover) – this was considered as a “reference” solution (REF),
- 2) using the official ZTDs provided by the ASG-EUPOS system, fixed for the reference stations and interpolated to the rover receiver (ASG),
- 3) using NRT ZTD estimates based on reference station GNSS data (NRT),
- 4) using NRT ZTD estimates based on meteorological data and Saastamoinen model (S+M),
- 5) using UNB3m troposphere model (UNB3m).

Analyzed parameters:

- Coordinate residuals with respect to the reference position (dN, dE, dH) and their mean values (Fig. 5, Table 1).
- Coordinate standard deviation (repeatability) (STD_N, STD_E, STD_H)
- % of sessions with validated ambiguity selection using W-ratio test with 2.0 threshold (AVSR – Ambiguity Resolution and Validation Success Rate)
- % of sessions with ambiguity validation failure (AVF – Ambiguity Validation Failure) - when wrong ambiguities passed the validation test.

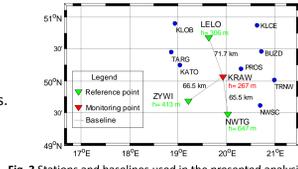


Fig. 3 Stations and baselines used in the presented analysis

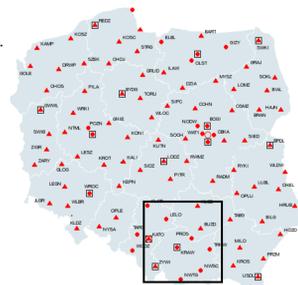


Fig. 4 Location of the test network in Poland

NEAR-REAL TIME TROPOSPHERE MODELLING

(Strategy 3)

NRT ZTD's coming from WUELS (Wrocław University of Environmental and Life Sciences) are based on real-time streams of GNSS data from ASG-EUPOS network (100 stations) as well as from selected EPN fiducial stations and EPN stations close to the Polish border (25 stations). The ZTD estimation procedure is based on processing of double-differenced carrier phase data with Bernese GPS Software 5.0 in hourly batch mode. Processing scheme utilizes recent IGS ultra-rapid products (ERP, SP3c). Solution of all baselines is based on resolving phase ambiguities with SIGMA strategy first on L5 (wide-lane) and then on L3 (narrow-lane) with introduction of already resolved L5 ambiguities. Tropospheric delay is estimated using a-priori Dry Niell model and mapping function and estimation of site specific parameters using Wet Niell mapping function. Compatibility with hourly ASG-EUPOS ZTD final solution derived with the usage of daily RINEX data and Rapid IGS products by the Military University of Technology Analysis Center (MUT-AC) is on the average level of 20 mm.

(Strategy 4)

ZTD model based on interpolated meteorological data (S+M) for the area of Poland is built according to the Saastamoinen model fed with the data coming from ASG-EUPOS meteo stations (~15 stations) as well as from Polish SYNOP and METAR meteo sensors. Atmospheric parameters (temperature, air pressure and relative humidity) are then interpolated for locations of all the ASG-EUPOS stations. The value of the particular parameter is calculated as a weighted average where the values of weights are calculated using empirical formulas differently for temperature, humidity and pressure (Fig. 2).

Table 1 The statistics of the positioning results obtained with the application of different troposphere (ZTD) models. (dN, dE, dU, mean residuals with respect to the reference position, STD – residual standard deviation (repeatability), AVSR – ambiguity resolution and validation success ratio, AVF – ambiguity validation failure ratio).

NWTG-KRAW	dN [m]	dE [m]	dU [m]	STD [m]	STD [m]	STD [m]	AVSR [%]	AVF [%]
REF (1)	-0.006	0.003	-0.016	0.010	0.007	0.019	81.9	2.1
ASG (2)	-0.006	0.003	-0.004	0.011	0.007	0.025	83.3	1.4
NRT (3)	-0.005	0.003	-0.028	0.010	0.007	0.018	82.6	1.4
S+M (4)	-0.007	0.002	0.084	0.013	0.009	0.038	34.7	9.0
UNB3 (5)	-0.007	0.003	-0.025	0.010	0.007	0.023	83.3	1.4

LELO-KRAW	dN [m]	dE [m]	dU [m]	STD [m]	STD [m]	STD [m]	AVSR [%]	AVF [%]
REF(1)	-0.004	-0.003	-0.013	0.009	0.005	0.017	83.3	2.1
ASG (2)	-0.005	-0.003	0.000	0.009	0.005	0.016	81.9	2.8
NRT (3)	-0.004	-0.003	-0.007	0.008	0.005	0.021	89.6	1.4
S+M (4)	-0.005	-0.002	-0.045	0.009	0.005	0.018	83.3	1.4
UNB3 (5)	-0.003	-0.003	-0.004	0.009	0.005	0.019	84.0	2.1

Multi-baseline	dN [m]	dE [m]	dU [m]	STD [m]	STD [m]	STD [m]	AVSR [%]	AVF [%]
REF (1)	-0.006	0.001	-0.011	0.007	0.005	0.016	91.0	0.0
ASG (2)	-0.006	0.001	0.003	0.008	0.006	0.016	89.6	0.0
NRT (3)	-0.006	0.001	-0.018	0.007	0.005	0.015	86.8	0.0
S+M (4)	-0.005	-0.000	-0.055	0.011	0.007	0.041	31.9	2.8
UNB3 (5)	-0.006	0.000	-0.013	0.007	0.005	0.016	86.8	0.0

RESULTS AND SUMMARY

- The most noticeable effect is observed in the station height component residuals, yet, in some extreme cases, mismodeling of the tropospheric delays may even disrupt ambiguity resolution and, therefore, prevents user from obtaining any position.
- It was shown that the ZTD obtained from the current implementation of the NRT processing presents good quality and NRT results are in a good agreement with REF, ASG, and UNB3m solutions. Ambiguity resolution success rate (AVSR) for these strategies is very similar and relatively high for single baseline (AVSR = 81.9 – 84.0 %) and multi-baseline solutions (AVSR = 86.8-91.0% Table 1).
- S+M troposphere modeling brings significantly worse results regarding both coordinate repeatability and ambiguity resolution and cannot be recommended for precise positioning.
- Multi-baseline processing allows for the highest ambiguity resolution success and also for very high reliability of the fast-static positioning.
- Comparing near real-time products – NRT vs. S+M strategies – it can be concluded that ZTDs derived in near real-time from the reference network GNSS data gives much better results, this was confirmed by fast-static positioning results presented here.
- It should be noted that in all the tests presented here, the ZTD estimates were tightly constrained in the positioning solution. Releasing constraints imposed on the ZTDs clearly improves the results, however, the aim of these research was to study the influence of the different ZTD modeling techniques on the positioning results, and tight constraints allowed for better discrimination between the models.

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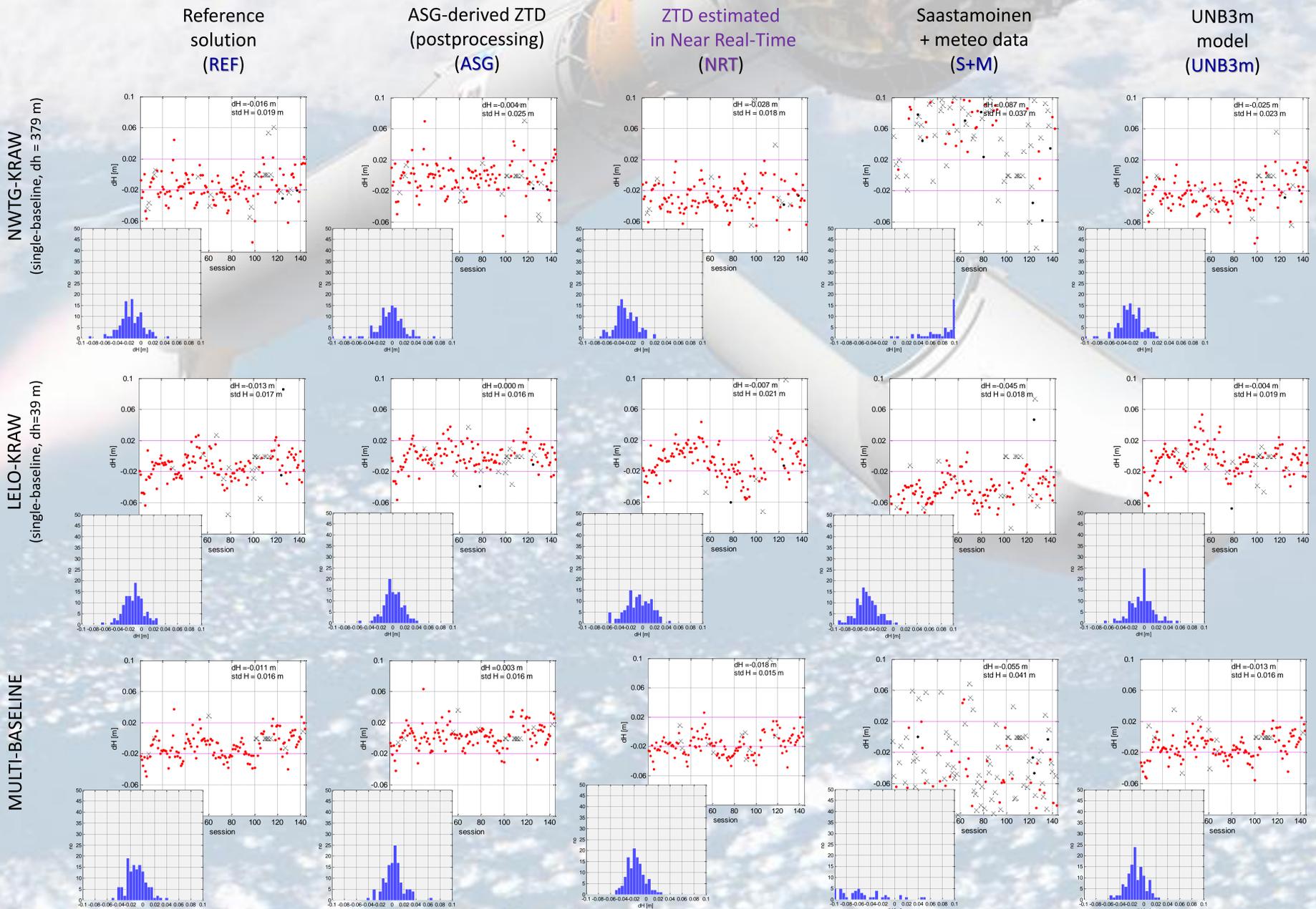


Fig. 5 Height component residuals and their histograms derived with the application of different troposphere/ZTD models in single- and multi-baseline modes.